

DOES FISHING PRESSURE AFFECT THE FEEDING ECOLOGY OF SEA SNAKES?

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Shawn Dsouza, Research Assistant

Chetan Rao, Programme Officer

Muralidharan M., Field Director

Biodiversity and Resource Monitoring – Flagships Program, Dakshin Foundation.



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ABOUT DAKSHIN FOUNDATION

Dakshin Foundation is a registered not-for-profit, non-governmental organization. Since its establishment in 2008, we have undertaken a range of projects that deal with conservation. Dakshin works with an understanding that challenges of conserving our environment is one that necessitates an active engagement between the natural and social sciences where conservationists accommodate expertise that transcends disciplinary boundaries. Dakshin's applied scientific research aims at filling some of the critical gaps in our current knowledge of marine ecosystems. Through long-term monitoring of select ecosystems and taxa, our research aims to advance our understanding of the patterns and processes that maintain ecosystem function and resilience to anthropogenic stress and climate-induced changes.

INTRODUCTION AND BACKGROUND

Humans have been venturing out to sea to gather food for thousands of years. Over those years, the methods of fishing have changed and have become efficient at gathering these resources. However, with these technological innovations, new issues have emerged. Today, the global fishing industry is faced with a crisis of sustainability with problems such as overexploitation and bycatch at the forefront (Ababouch et al. 2016; Agardy 2000).

Gear selectivity is a major issue for fisheries today due to the accidental catch of non – commercial species. This phenomenon has been termed as ‘bycatch’ (Alverson et al. 1994; Hall, Alverson, and Metuzals 2000; Davis 2002). Bycatch threatens populations of marine megafauna such as sea turtles in trawl nets and longlines and sharks in long-line tuna fisheries (Cambiè et al. 2013; Molina and Cooke 2012). Understanding bycatch to mitigate its effects is a major step towards implementing ecosystem based fisheries management and ensuring fisheries sustainability (Zhou 2008; Trochta et al. 2018).

Bycatch related mortalities are apparent in fisheries around the world and its effects on populations have been studied extensively (Molina and Cooke 2012; Fry, Milton, and Wassenberg 2001; Milton 2001). However, there are multiple non – lethal effects and indirect fisheries interactions that go largely unnoticed (Wilson et al. 2014). These can include behavioural changes in predators and their prey, increased physiological stress and alteration of entire coastal food webs (Ryer 2002; Revuelta et al. 2018; Díaz López 2018; Jackson et al. 2001).

Predators are vital in regulating ecosystem processes through top-down forcing (Paine 1966; Schmitz 2007). The selective removal of top predators from ecosystems can have far ranging effects on the lower trophic levels including regime shifts and mesopredator release (Myers et al. 2007). Resource availability also plays a comparable role in maintaining ecosystem stability through bottom up processes such as competition (Schoener 1968; 1974). These trophic forces work together to maintain biodiversity and other local ecosystem processes such as nutrient turn over (Terborgh 2015).

Sea snakes are a recent and diverse lineage of marine reptiles. They belong predominantly to the *Hydrophiid* lineage in the family Elapidae. They are found throughout shallow coastal waters in the tropics with exception of the Atlantic Ocean (Bonnet, Rasmussen, and Brischoux 2016; Dunson 2000). Sea snakes play an important role in maintaining the trophic structure of

coastal ecosystems through their role as mesopredators (Voris 1972). Fisheries pose a major threat to sea snakes throughout their range, with mortality due to bycatch playing a major role in observed declines over the past two decades (Elfes et al. 2013). The implication of these local extirpations is still unknown. In addition, the effects of fisheries interactions on sea snake physiology and ecology is not fully understood.



Study species: Beaked sea snake (*Hydrophis schistosus*, A) and Shaw's sea snake (*H. curtus*, B)

Dakshin Foundation has been working in the Sindhudurg district of Maharashtra since 2016, studying species diversity in sea snakes in the region. Our work has primarily focused on the bycatch of sea snakes in gillnet and trawl fisheries operating in Malvan (Rao et al. 2017). We observed multiple species of sea snakes caught in both gears with *Hydrophis schistosus* and *H. curtus* being the most abundant. We observed high mortalities in both the species; however, *H. curtus* was more vulnerable to bycatch mortality. In addition, we observed that the species assemblage of sea snakes in bycatch on the west coast has changed drastically in the last two decades with large declines in the proportion of *H. curtus* (Rao et al, in review). However, the reasons for these declines are still not well understood.

To study interactions between fisherman and sea snakes from an ecological perspective, we asked the following questions:

1. Does resource use differ between *Hydrophis curtus* and *H. schistosus* off the Sindhudurg coast?
2. Does resource use in sea snakes vary by sex and developmental stage?
3. Are sea snake prey species commercially important and to what extent?
4. If so, how does this overlap affect interspecific and intraspecific interactions among sea snakes?

METHODS AND CHALLENGES

We use a combination of stable isotope analysis and visual gut content analysis to describe patterns of inter and intraspecific resource use and contrast the same with previous studies on sea snakes.

We carried out field observations and collections in two phases; January 2018 – April 2018 and November 2018 – May 2019. We chose the Sindhudurg district of Maharashtra given our ongoing long-term engagement in the region (Rao et al. 2017). The bulk of our field observations were carried out in Malvan, along with brief surveys in the villages on Tambaldeg and Vayangani (Figure 1)

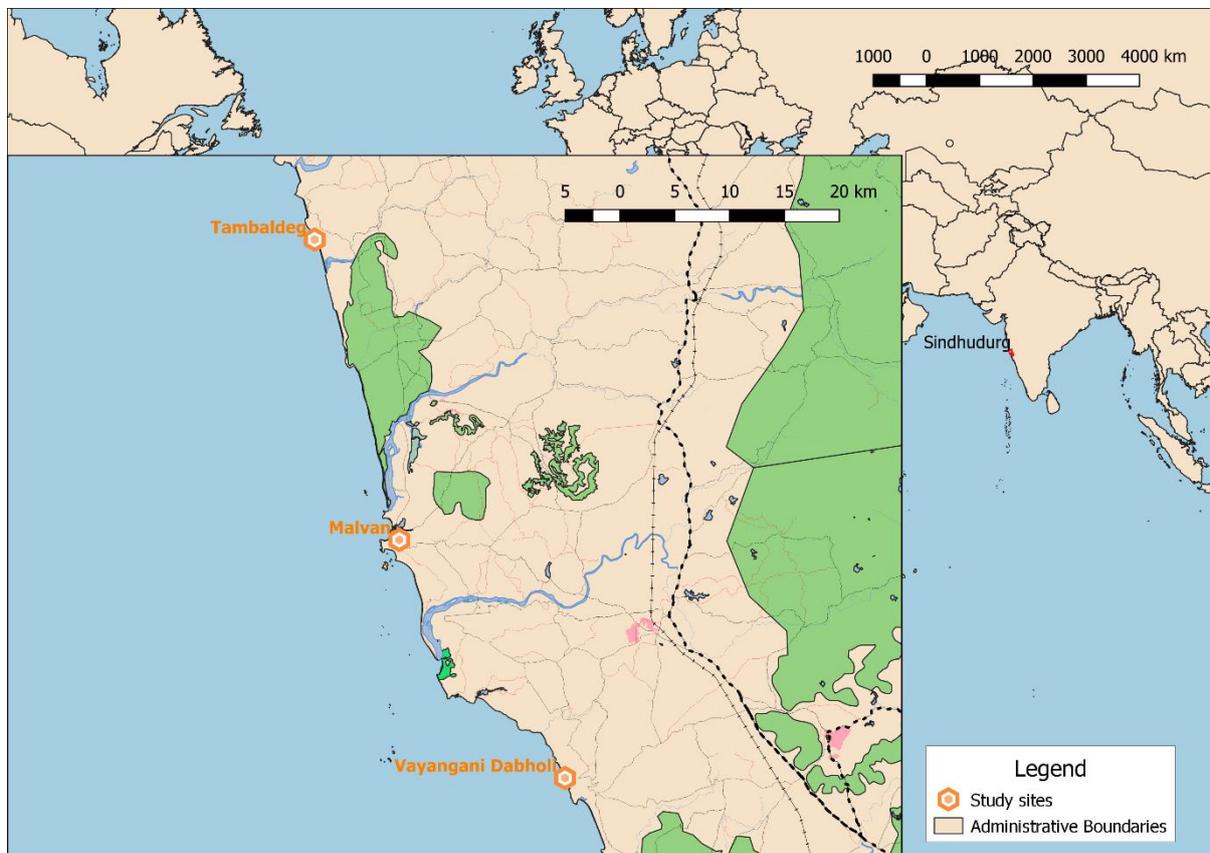


Figure 1: Map of study sites.

Malvan is a busy fishing town with multiple gears operating at once. We focused our sampling mainly on gillnets and trawlers operating out of the port. Vayangani and Tambaldeg are both hamlets with limited small-scale fishing in the inshore waters (Karnad, Gangal, and Karanth 2014). However, trawlers operate throughout the district, hence even these smaller villages are characterised by moderate to high fishing pressure (Figure 1).

SAMPLING

BOAT BASED SURVEYS



Boat based sampling at Vayangani.

We carried out surveys between 3:00 – 6:00 and 19:00 – 23:00, using a locally hired boat (28 ft, out board motor). We used a modified point survey methodology with randomly placed points in a 2km X 1km quadrant laid in the survey area (Figure 2). Each point was visited and surveyed for 10 mins. 4 LED panels powered by a 12-volt lead battery were outfitted to the boat, two on each side. Sea snakes attracted by the lights were observed and recorded to the lowest possible taxonomic level. We also collected environmental variables such as water temperature, air temperature, wind speed and depth at each point (Udyawer et al. 2016).



Figure 2: Example of sampled area and random points placed for boat-based sampling.

FISHERIES DEPENDENT SAMPLING

Sea snakes were collected from gillnets and trawlers at the time when the boats landed. Fishing and gear information such as haul time, depth, substrate, etc. were recorded at the time of collection.



Sea snake caught in a gill net at Malvan.

TISSUE SAMPLING AND MORPHOMETRIC MEASUREMENTS

Blood samples from the caudal vein were taken from live snakes using a 20G 0.7mm x 20mm heparinised syringe and collected in a heparinised centrifuge tube (Lemons et al. 2012; Moore, Lemaster, and Mason 2000). The samples were then centrifuged at 10,000 rpm for 10 mins and the plasma is separated and stored in a different vial. Samples were stored at – 20 deg. Celsius until processing. Scale samples were taken from dead snakes and stored in 99% alcohol until processing. Sea snakes were measured (snout to vent length and body length) and weighed. All live snakes were released after sampling and measurement.

VISUAL GUT CONTENT ANALYSIS



Puffer fish extracted from sea snake gut.

Presence of gut content was visually assessed and regurgitated gut content was collected, identified and measured (Lobo, Vasudevan, and Pandav 2005). For dead snakes, gut content was extracted by dissection. Specimens were scored on a scale from 1 to 4 based on the level of digestion (Table 1). Tail tissue samples were collected for all gut content specimens.

Specimen score	Description
1	Intact specimen
2	Head partially digested
3	Head completely digested; body partially digested.
4	Specimen completely digested, unidentifiable mass/ bones

Table 1: Condition scores for gut content specimens

CATCH MONITORING AND SAMPLING

Catch from random vessels (trawlers and gillnets) were characterised (composition and biomass) to build the trophic niche of fisheries (Mashjoo, Jamebozorgi, and Kamrani 2018). The 20 most abundant fish of reasonable size (i.e. with respect to gape of sea snakes and other mesopredators) caught in gillnets, trawlers and beach seines were sampled for tail tissue, weighed and measured.

STABLE ISOTOPE ANALYSIS

Tissue samples collected from snakes and fish specimens were preserved and frozen before being taken to the lab. Blood samples were centrifuged to separate blood cells from plasma and

stored in a freezer. Scale and fish fin samples were stored in 70% ethanol. The preservatives were then decanted in the lab before drying all samples in an oven at 50°C for 72 - 96 hours. Dried samples were then pulverised and homogenised using a mortar and pestle. We carried out lipid extraction using the Bligh and Dyer (1959) method for only sea snake scale samples as high lipid content can confound comparison carbon isotope data among samples (Post et al. 2007). Lipid extraction was carried out for high lipid content samples only such as sea snake scale samples and not for low lipid content samples such as fish fins and blood plasma (Figure 3). Processed samples were sent to the labs at University of Agricultural Sciences, Bangalore and Centre for Earth Sciences, Indian Institute of Science, Bangalore for Isotope Ratio Mass Spectroscopy.

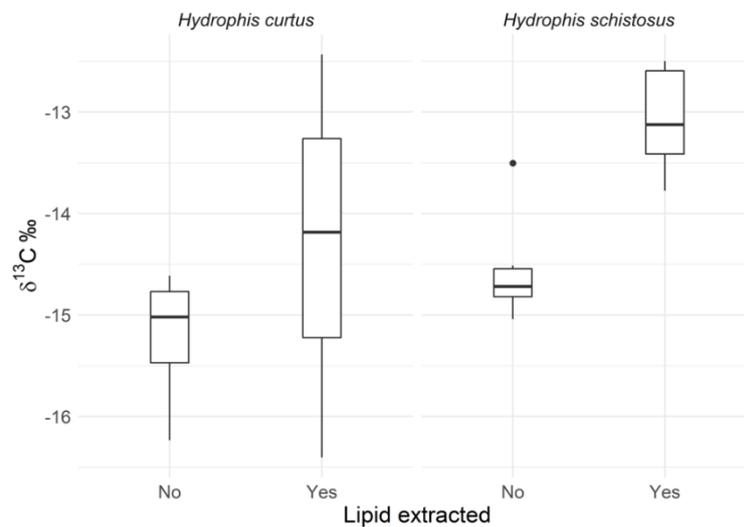


Figure 3: Effects of lipid extraction on $\delta^{13}\text{C}$ from sea snake scales.

DATA ANALYSIS

We analysed our data in R 3.5.2. We used diversity and similarity indices from the ‘vegetarian’ package to compare dietary range and overlap between and within sea snake species (Schoener 1968; Jost 2006). We used parametric t – tests and the Kruskal – Wallis non parametric test to compare prey morphometrics across groups.

For stable isotope analysis, we used the SIBER package (Jackson et al. 2011). We used a Bayesian model to estimate parameters (isotopic means and variance – covariance matrices) for standard ellipses and computed standard ellipse area (SEA) to compare niche width among groups. We calculated probability of niche width difference on posterior distributions of SEA. We also used posteriors of estimated ellipses to calculate overlap in isotopic niche. We used a linear model to test the effect of SVL on isotope ratios of both plasma and scales.

We computed relative proportions of various fish and invertebrate families in samples from gill net and trawler landings. We used the sample proportions to calculate catch composition over the sampling period and compared each gear to sea snake diet.

CHALLENGES

We faced a number of logistical issues during the implementation of the project, the foremost being bad weather and unsuitable sea conditions making boat-based sampling difficult for most of our field work. In addition, our original control site, Tambaldeg, did not have appropriate topography for conducting regular boat surveys. We are thus, unable to present detailed findings of our boat surveys, and have included the protocols developed over the course of the field work. Due to delays with the isotope ratio mass spectrometry, we are only able to present preliminary results of our stable isotope analysis. We are working on completing our analysis in the coming months.

KEY FINDINGS AND RESULTS

A total of 793 snakes were sampled from gillnets (254.71 haul hours) and trawl nets (567.91 haul hours) in two field phases between January 2018 and May 2019. *Hydrophis schistosus* was the most abundant (76.29%) followed by *Hydrophis curtus* (22.5%). We also found 3 other species; *H. cyanocintus*, *H. caerulescens* and *H. viperinus* sporadically in the catch. We collected scale and plasma samples from a subsample of the dominant species (Table 2); however, we were able to analyse only a subset of the samples this time.

Species	No. of samples collected		No. of samples analysed	
	Scales	Plasma	Scales	Plasma
<i>Hydrophis curtus</i>	28	29	12	5
<i>Hydrophis schistosus</i>	49	107	23	25

Table 2: Number of tissue samples collected and analysed (IRMS) for each snake species.

Of the snakes encountered, 129 had some gut content present in their digestive tracts (36 – HC, 93 – HS). We identified 57.9% of the specimens to specific level (27 prey species) and 69.3% to family level (19 families) from sea snake gut contents. A large proportion of the gut content observed was unidentifiable beyond the family level. We considered only specimens with a condition score of less than 3 (Table 1) for morphometric analysis. We collected a total 249 fin samples from 60 species (31 families) for stable isotope analysis; we are currently in the process of analysing the samples.

RESOURCE PARTIONING BETWEEN *H. SCHISITOSUS* AND *H. CURTUS*

We identified a greater number of prey families in the diet of *H. schistosus* (14 families) than *H. curtus* (11 families, Figure 4). *H. schistosus* fed predominantly on a single family, Tetraodontidae, comprising 34.93% of specimens collected. Plotosids, Ariids and Clupiids made up 19.4 % of *H. schistosus* diet. We did not find such dominance/preference of prey families in the *H. curtus* diet. Hence, second order prey diversity (Shannon Index) was lower in *H. schistosus* gut content (6.72 ± 0.86) than in *H. curtus* (9 ± 0.91). Seven fish families were found to be predated by both snake species (Morista – Horn Similarity = 0.25 ± 0.1).

Prey size did not vary significantly with SVL for either species; however, sample sizes for the comparison were low. Prey length and weight were not significantly different among species. However, we found that *H. schistosus* predated on individuals with higher maximum body girth (Table 3, $p < 0.05$).

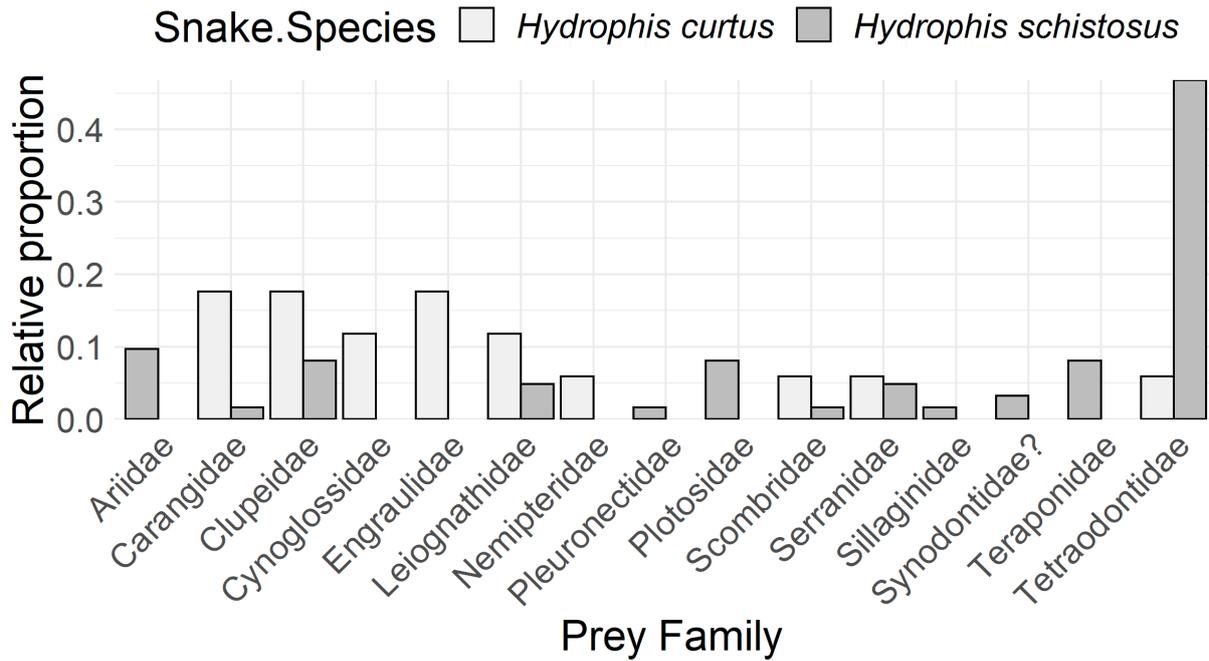


Figure 4: Relative proportions of prey families in gut content of sea snakes.

Snake Species	Sample Size	Prey Length (cm) ± SD	Prey Weight (g) ± SD	Prey Girth (cm) ± SD*
<i>H. schistosus</i>	32	11.83±3.96	31.15±19.81	3.57±1.1
<i>H. curtus</i>	11	9.65±3.92	21.3±19.45	2.76±0.79

Table 3: Size of prey specimens observed in gut content of *H. schistosus* and *H. curtus*. *Prey girth was found to be significantly different ($p < 0.05$).

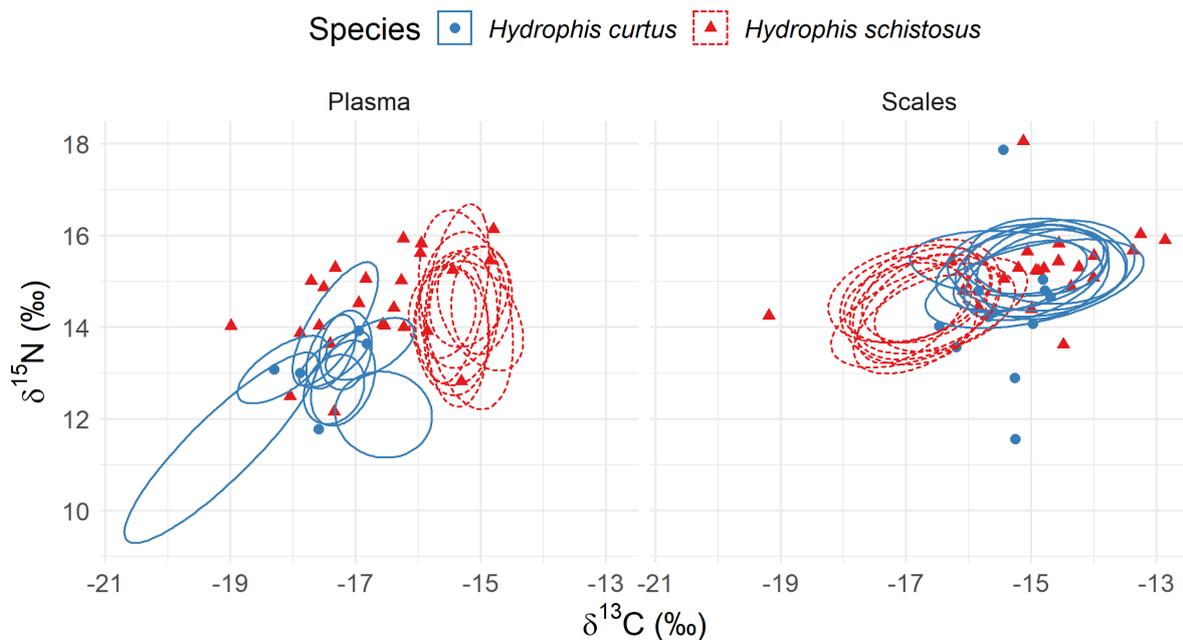


Figure 5: Posterior standard ellipses ($n = 10$) depicting isotopic niches of *H. schistosus* and *H. curtus*.

Species	Tissue	$\delta^{13}\text{C} \pm \text{SD}$	$\delta^{15}\text{N} \pm \text{SD}$
<i>Hydrophis curtus</i>	Plasma	-17.51±0.63	13.09±0.83
	Scales	-15.42±0.57	14.32±1.48
<i>Hydrophis schistosus</i>	Plasma	-16.77±1.14	14.48±1.06
	Scales	-14.93±1.28	15.29±0.85

Table 4: Mean (\pm SD) isotopic values for plasma and scales of both sea snake species.

Standard ellipses show that both species occupy similar positions in isotopic space (Figure 5). However, larger sample size in *H. schistosus* may contribute to greater apparent variability (and hence uncertainty) in ellipse estimation when compared to *H. curtus*. In addition, isotope values show enrichment in scale tissues in both species when compared to plasma (Table 4, Figure 5).

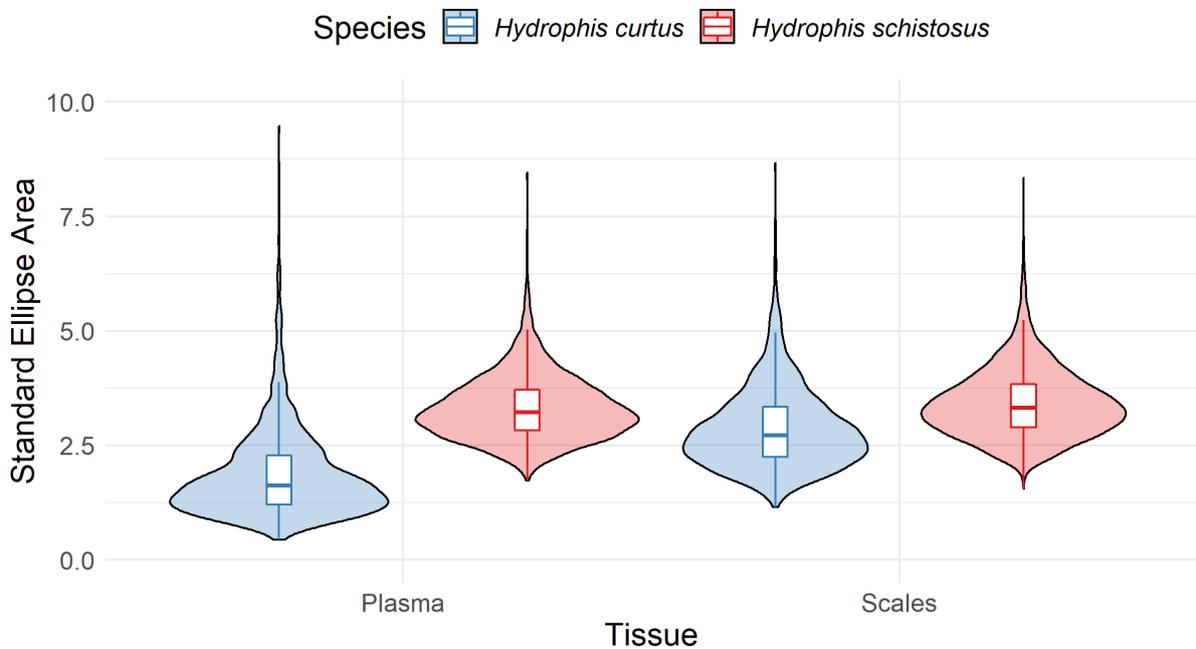


Figure 6: Comparing SEA (isotopic niche width) computed from posterior ellipses across sea snake species and tissues

Standard ellipse area (SEA) is larger in *H. schistosus* than *H. curtus* for both scales ($P = 0.47$) and plasma ($P = 0.82$, Figure 6). The posterior distribution of SEA has a right skewed long tail (masked by the limits of the graph for visual clarity) possibly due to the low sample size. SEA is slightly larger in scales ($\text{SEA} = 3.41 \pm 0.75$) compared to plasma (1.89 ± 1.1) in *H. curtus* ($P = 0.9$); however, both tissues exhibit similar SEA in *H. schistosus*. Overlap between *H. curtus* and *H. schistosus* seems to be higher when comparing long term resource use (scales, 0.4 ± 0.06) than in the short term (plasma, 0.1 ± 0.08).

RESOURCE PARTITIONING WITHIN SPECIES

Sample sizes to compare across sexes were fairly low for *H. curtus* (18 males and 18 females) but were adequate for *H. schistosus* (56 males and 36 females). Gut contents of males and females of both species exhibited a similar range and diversity in prey families (Figure 7). However, females of both species had higher number of prey families in their gut. *H. schistosus* exhibited a greater overlap in gut content across sexes than *H. curtus* (Table 5). We observed that females of both species on average predated on larger prey; however, the differences were not statistically significant for any of the morphometric measurements due to low sample sizes (Table 6).

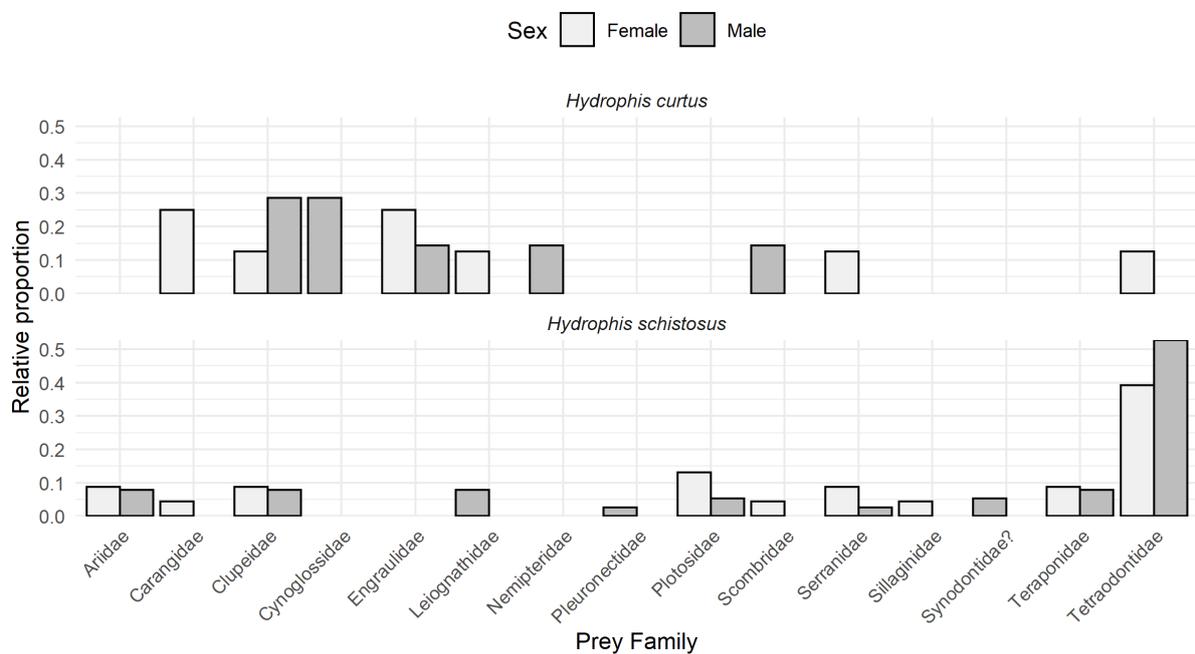


Figure 7: Relative proportion of prey family in gut contents of sea snakes compared across sexes.

Species	Sex	Sample size	Prey family richness	Prey family diversity \pm SE	Morista – Horn similarity \pm SE
<i>H. schistosus</i>	Male	55	7	5 \pm 0.82	0.89 \pm 0.1
	Female	36	10	7.2 \pm 1.06	
<i>H. curtus</i>	Male	18	5	6.61 \pm 0.89	0.48 \pm 0.09
	Female	18	7	6.59 \pm 0.83	

Table 5: Descriptive statistics comparing intra specific diet partitioning. Bootstrap errors have been computed for diversity and similarity metrics.

Species	Sex	Sample size	Prey standard length (cm) \pm SD	Prey Weight (g) \pm SD	Prey girth (cm) \pm SD
<i>H. schistosus</i>	Male	18	10.77 \pm 3.86	27.16 \pm 19.04	3.3 \pm 1.21
	Female	13	13.13 \pm 3.93	35.36 \pm 20.82	3.98 \pm 0.88
<i>H. curtus</i>	Male	6	8.31 \pm 3.5	16 \pm 21.88	2.51 \pm 0.5
	Female	5	11.26 \pm 4.16	26.6 \pm 17.38	3.06 \pm 1.04

Table 6: Morphometric comparison of gut content specimens by sex.

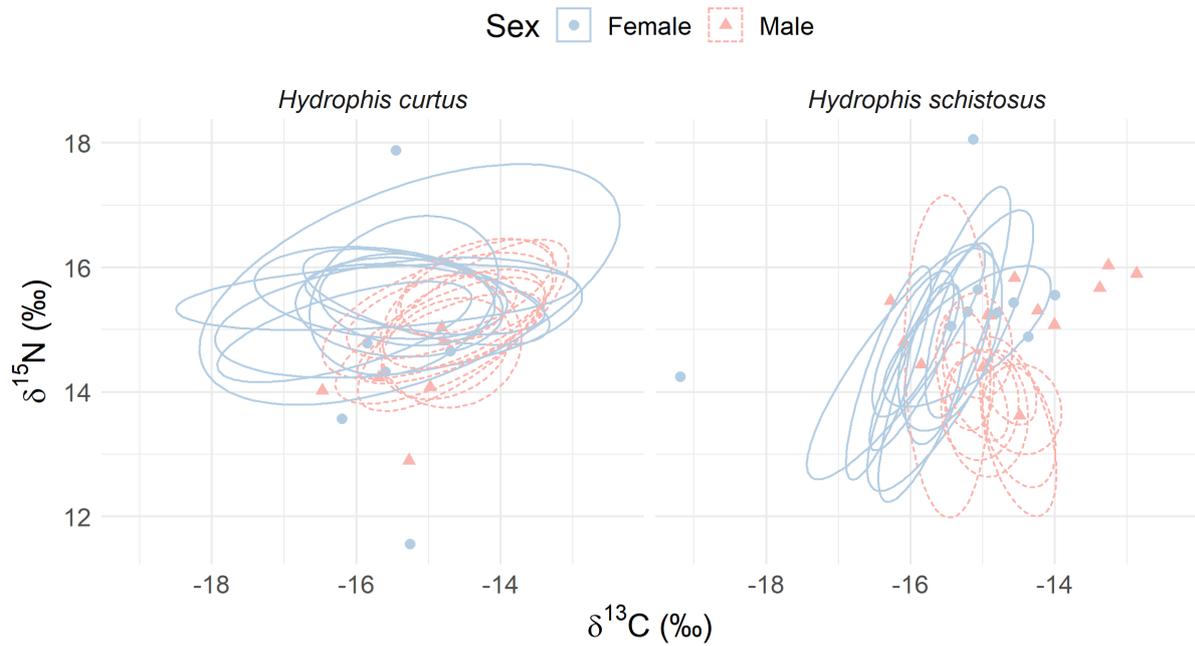


Figure 8: Posterior standard ellipses comparing isotopic niche among sexes within species.

Species	Isotope	Term	Estimate	Standard error	p - value
<i>Hydrophis schistosus</i>	$\delta^{13}\text{C}$	(Intercept)	-16.954	1.689	0
		SVL (mm)	0.024	0.020	0.239
	$\delta^{15}\text{N}$	(Intercept)	14.415	1.197	0
		SVL (mm)	0.010	0.014	0.466
<i>Hydrophis curtus</i>	$\delta^{13}\text{C}$	(Intercept)	-13.713	1.786	0
		SVL (mm)	-0.028	0.029	0.359
	$\delta^{15}\text{N}$	(Intercept)	11.842	4.824	0.033
		SVL (mm)	0.040	0.078	0.616

Table 7: Model summary comparing change in isotope ratios with SVL (mm).

Sample size for plasma was low for all groups (sexes in each species) and hence has been omitted from analysis. Males and females of both species occupy similar isotopic niches; however, uncertainty of estimation is high due to low sample sizes (Figure 8). SEA is slightly larger for both females of both species; it is more prominent in *H. curtus* ($P = 0.83$) than *H. schistosus* ($P = 0.66$). The posterior distribution of SEA has a right skewed long tail (masked by the limits of the graph for visual clarity) possibly due to the low sample size (Figure 9). Overlap in isotopic niche is higher in *H. curtus* (0.42 ± 0.1) compared to *H. schistosus* (0.18 ± 0.12).

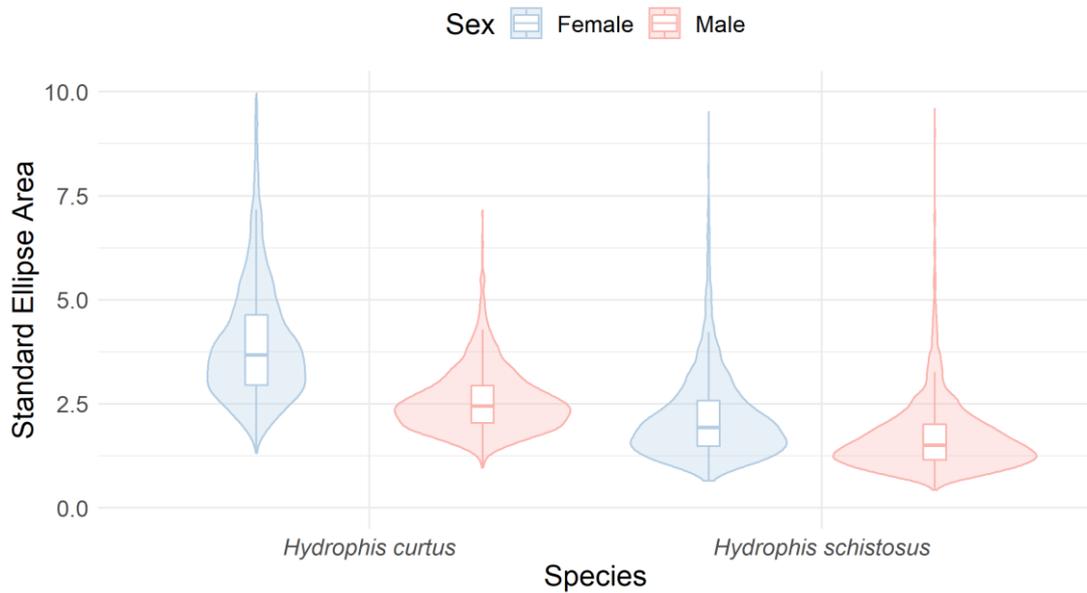


Figure 9: Comparing standard ellipse area (niche width) computed from posterior ellipses among sexes within species.

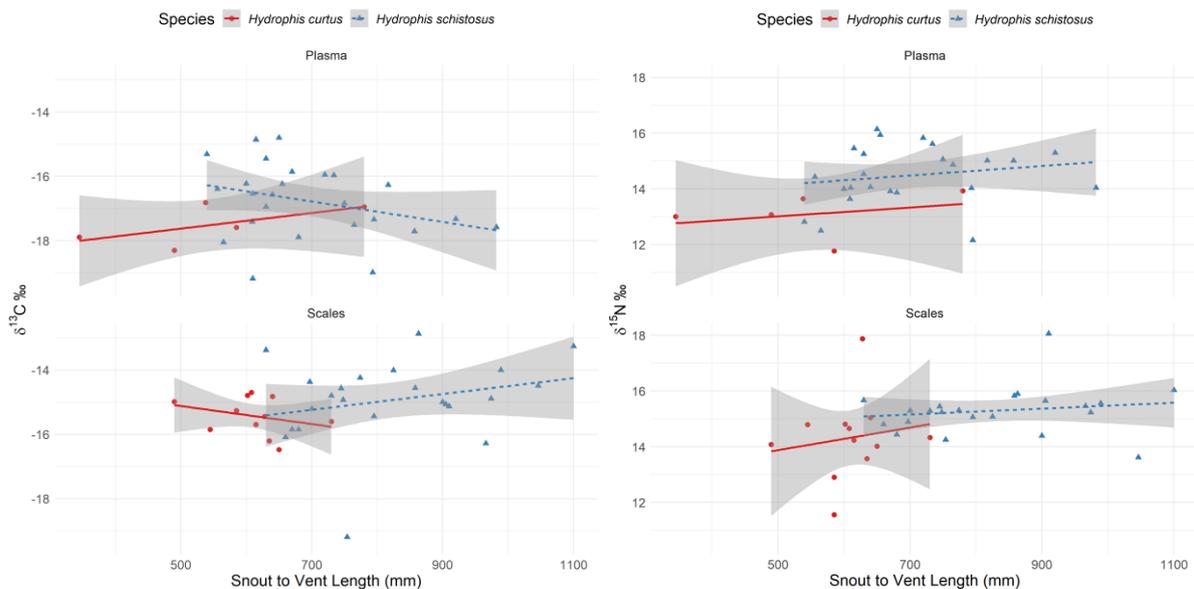


Figure 10: Comparing change in isotope ratios with SVL (mm).

Our VGCA sampling was not adequate to compare diets and prey preference across developmental stages. Snout to vent length (mm) had little effect on $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ (Figure 10, Table 7).

RESOURCE OVERLAP BETWEEN SEA SNAKES AND FISHERIES

Snake Species	No. of prey families recorded	No. of prey families targeted by trawlers	Prey families targeted by gillnets
<i>H. curtus</i>	10	9	7
<i>H. schistosus</i>	13	9	7

Table 8: Overlap in catches of trawlers and gill nets with sea snake prey species.

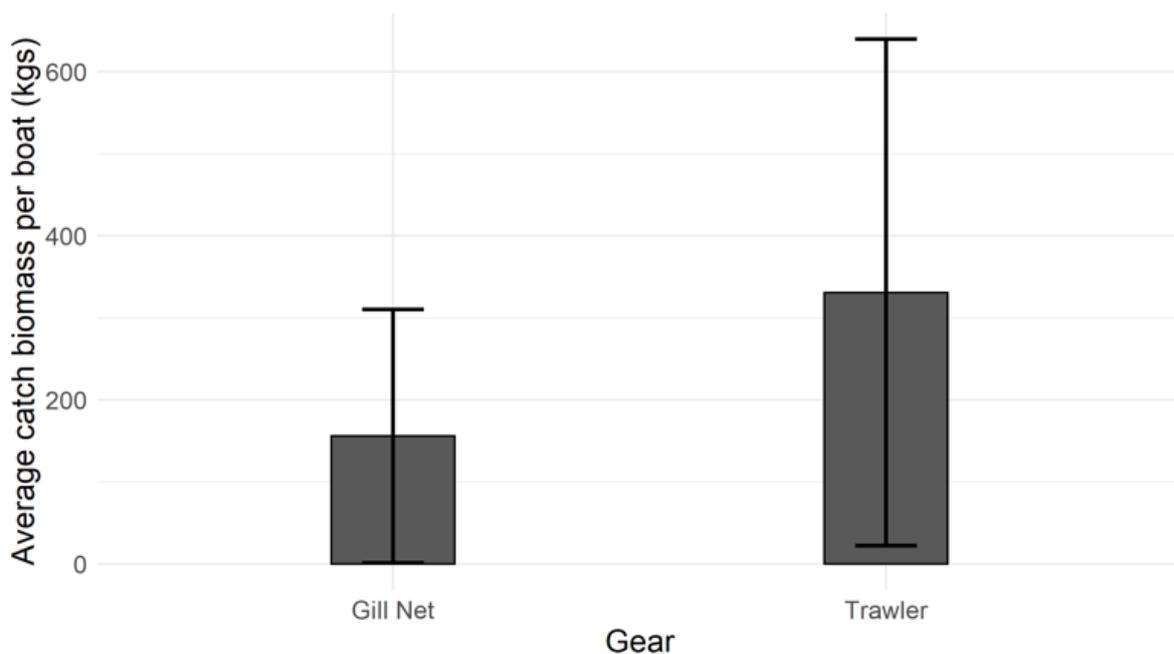


Figure 11: Average catch biomass per sample in gill nets and trawlers, error bars indicate standard deviation.

We sampled 38 gillnets (35.41 haul hours) and 162 trawler (835.3 haul hours) landings. There was high variation in biomass landed by both gears (Figure 11). On average, trawler catch consisted of 75.97% low value bycatch by weight, belonging to 49 families in total. Gillnets on the other hand targeted 15 families. A large proportion of sea snake prey families were caught by both gears (Table 8). These species were of high relative importance to both fisheries

and sea snakes, comprising a high proportion of the commercial landings (Figure 4 & 12).

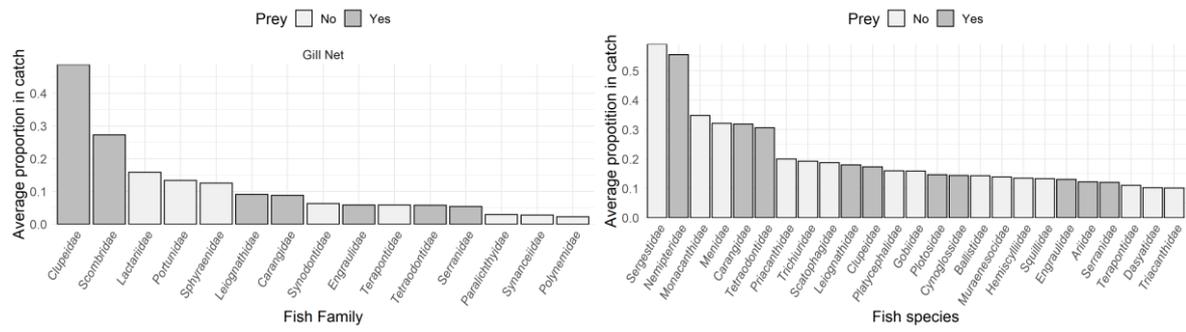


Figure 12: Fish families found in gillnet (left) and trawler (right) catches. Sea snake prey families are marked in blue. Only the top 10% of trawler catches are represented for readability.

DISCUSSIONS, IMPLICATIONS, CONCLUSION AND WAY FORWARD

Our study is the first comprehensive account of sea snake trophic ecology along the west coast of India in over a decade (Lobo, Vasudevan, and Pandav 2005). We also studied sub-lethal interactions between sea snakes and fisheries and explored the possible effects of the same on their ecology and behaviour. While preliminary, our data reveals dynamics of intraspecific and interspecific resource partitioning in sympatric sea snakes. We also found that prey species, vital to sea snakes are targeted widely by both trawlers and gillnets.

Most sea snake species have evolved to be trophic or habitat specialists. However, the degree of specialisation may vary and so may modes of predation (Glodek and Voris 1982). These may include cruising, browsing and even ambush predation (Brischoux and Shine 2011). A notable exception is *Hydrophis curtus*, which has been observed to be a generalist (Lobo, Vasudevan, and Pandav 2005). *H. schistosus* on the other hand is a known pufferfish and cat fish specialist (Voris, Voris, and Liat 1978). While our findings align with previous studies to some extent, we also observed that *H. schistosus* had a greater isotopic niche width than *H. curtus* possibly a result in the greater range of prey taken by this species or greater isotopic variation in its prey base (Figure 4 & 9).

McCosker (1975) observed low overlap between sympatric species in Australian reefs. These reefs are extreme diverse in terms of Hydrophids and Laticaudid, compared to the fairly depauperate west continental shelf of India. Hence, the high overlap between these two dominant species may be an artefact of *H. schistosus* filling available niches as they encounter them (Schoener 1974). Both species are also sympatric throughout their range (Glodek and Voris 1982). Glodek and Voris (2010) found that while *H. schistosus* occupies a fairly distinct niche in terms of diet and habitat in species rich sea snake communities, *H. curtus* tends to overlap heavily with other species sympatric with it. Our data suggests that the two species may be partitioning prey by size, with *H. schistosus* targeting larger prey overall (Table 2). This is common among snake species that are limited by gape with the type of prey they can ingest (Shine 1991b). *H. schistosus* has been observed taking prey that are twice the diameter of their necks and has the largest gape to body size ratio compared to other Hydrophiids (Voris, Voris, and Liat 1978).

While our data and previous studies suggests that *H. schistosus* show a preference for Tetraodontids and Plotosids (Figure 3), the larger apparent range of its diet and higher isotopic niche width may be a function of its fairly opportunistic mode of hunting (Voris, Voris, and

Liat 1978). The increased range of potential prey may result in more variable isotopic signatures of *H. schistosus* tissue (Bearhop et al. 2004). Similarly, *H. curtus* has also been known as a sit and wait predator using the water column to opportunistically find prey. This is reflected by our data in terms of the greater diversity of specimens found in this species gut. Lobo (2005) also observed a similar trend, adding that gut composition also varied with time of day, lending support to this hypothesis. The smaller isotopic niche width of *H. curtus* may be an artefact of low sample sizes in our preliminary data (Table 2).

Both species exhibited low overlap in isotopic niche (space occupied on the isotope biplot depicted by standard ellipses, eg. Figure 5 & 8) among sexes indicating resource divergence. However, in terms of prey preference, both species show high similarity in gut content among sexes (Table 5). MacArthur and Levins (1964) proposed the principle of limiting similarity of resource use, stating that a species with similar resource use along one niche axes (eg. trophic axis) must partition themselves along other niche axes (eg. habitat) in order to reduce competitive pressure. Hence, while sexes among sea snakes may show high overlap in diet, the difference in isotopic niche may be due differing resource use along another niche axis. The apparent divergence may also be caused in part by different life history traits among sexes in Hydrophiids, such as females coming closer to shore before and during parturition and possible starvation during gestation. While prey size was not significantly different, we expect a difference in preference by sex as females are usually larger than males in most snake species (Shine 1991a).

Our sampling was not adequate to analyse resource use across developmental stages. However, our anecdotal observations suggest that *H. schistosus* juveniles feed on smaller individuals of the same prey base. Instead of comparing among developmental classes (neonates, juveniles and adults), we tested the effect of SVL on isotopic composition of sea snake tissues. As snakes grow throughout their lives, the animals' size is a good proxy for its age. We found no effect of SVL on both isotopic ratios indicating relative stability in the resource and habitat use for the SVL range we were able to test. However, we lack information for smaller individuals which may have differing resource use.

Lobo's (2005) study of the diet of *H. curtus* found in trawler bycatch observed an almost 75% overlap of *H. curtus* diet with trawler bycatch species. Our findings reveal the further threat of possible resource depletion by both trawlers and gill net fleets (Figure 6). On the other hand, Fry et al. (2001) found little to no overlap of sea snake bycatch species with bycatch from

prawn trawlers in Northern Australia. This may suggest a geographical trend in intensity of trophic interactions between sea snakes and fisheries. However, further investigation is necessary for conclusive inference.

Our observations suggest a scenario in which fisheries pose a two-fold threat to sea snakes and other coastal mesopredators. We hypothesise that fisheries may play a dual role as predator, through targeted removal or bycatch mortality as well as a large-scale competitor with uncontrolled exploitation leading to resource depletion (Rao et al. 2017). We suggest that resource depletion has a controlling effect on mesopredator release that can occur as a result of the local extinction of top predators, namely large sharks in this case (J. B. C. Jackson et al. 2001; Myers et al. 2007; Estes et al. 2011; Steneck 2012). Thus, fisheries may have a much larger effect on coastal food webs than previously thought.

Visual gut content analysis presents inherent biases due to the snapshot nature of the sampling and the requirement for large sample sizes (Newsome et al. 2007). As *H. curtus* is now inherently rare in the region (Rao et al. 2017), gaining the sample size necessary to make inferences with VGCA alone is challenging. While preliminary, stable isotope analysis has enabled meaningful insight into the ecology of these threatened and elusive species. Going forward, we hope to test hypotheses regarding possible niche shifts in sea snakes and other marine mesopredators in response to fishing intensity. We are also in the process of developing methodologies to use stable isotopes to study food web wide effects of fisheries, including constructing isotopic niches of fleets to quantify and compare overlap with important mesopredators. We hope to gain a better understanding of the ecological, physiological and population level effects of fisheries on mesopredators.

KEY OUTCOMES



Workshop with local stakeholders at Malvan.

Our work has been covered multiple times by local news outlets such as *Tarun Bharat* and *Mumbai Mirror*. Members of the team have also written popular articles to raise awareness about these issues with the public (listed below). We conducted outreach workshops with fishermen to communicate our findings with them and are currently planning further local engagements. We also created and distributed outreach materials in the form of a poster (Appendix C). In the coming months, we hope to publish our findings in the form of a peer reviewed journal paper and make our data open to other researchers. We also plan to continue our work in the Sindhudurg region and expand our research to other parts of the coast.

Popular Articles:

1. Creasey, M. and Dsouza, S. 2019. Sailing into an uncertain future. *Current Conservation*.
2. Dsouza, S. 2019. Scaly business: A day in the life of a sea snake ecologist. *Current Conservation*.
3. Rao. C. Serpents of the sea. *Hornbill*. August 2018. Print

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APPENDIX A: LIST OF SEA SNAKE PREY SPECIES OBSERVED IN GUT CONTENT

Snake Species	Prey Family	Prey Species	Percentage
<i>Hydrophis curtus</i>	Carangidae	<i>Alepes sp.</i>	15.38
	Carangidae	<i>Caranx heberi</i>	7.69
	Clupeidae	<i>Sardinella longiceps</i>	7.69
	Clupeidae	<i>Sardinella sp.</i>	15.38
	Engraulidae	<i>Thryssa dussumieri</i>	7.69
	Leiognathidae	<i>Leiognathus sp.</i>	15.38
	Nemipteridae	<i>Nemipteris sp.</i>	7.69
	Scombridae	<i>Rastrelliger kanagurta</i>	7.69
	Serranidae	<i>Epinephelus diacanthus</i>	7.69
	Tetraodontidae	<i>Lagocephalus inermis</i>	7.69
<i>Hydrophis schistosus</i>	Ariidae	<i>Arius caelatus</i>	1.89
	Ariidae	<i>Arius maculatus</i>	3.77
	Ariidae	<i>Arius sp.</i>	1.89
	Carangidae	<i>Megalapsis cordyla</i>	1.89
	Clupeidae	<i>Sardinella longiceps</i>	1.89
	Clupeidae	<i>Sardinella sp.</i>	5.66
	Leiognathidae	<i>Leiognathus brevirostris</i>	1.89
	Plotosidae	<i>Plotosus lineatus</i>	7.55
	Plotosidae	<i>Plotosus sp.</i>	1.89
	Scombridae	<i>Rastrelliger kanagurta</i>	1.89
	Serranidae	<i>Epinephelus diacanthus</i>	3.77
	Serranidae	<i>Epinephelus sp.</i>	1.89
	Sillaginidae	<i>Sillago sihama</i>	1.89
	Teraponidae	<i>Terapon puta</i>	3.77
	Teraponidae	<i>Terapon sp.</i>	1.89
	Teraponidae	<i>Terapon theraps</i>	3.77
	Tetraodontidae	<i>Arothron sp.</i>	3.77
	Tetraodontidae	<i>Chelonodon laticeps</i>	7.55
Tetraodontidae	<i>Lagocephalus inermis</i>	41.51	

सिंधुदुर्गातील समुद्री साप

स्थानिक नाव: मारझो
समुद्री सरपटणाऱ्या जीवांमधील समुद्री सापांमध्ये फार मोठ्या प्रमाणात विविधता आढळते. जगभरात समुद्री सापांच्या जवळजवळ साठ पेक्षा जास्त प्रजाती सापडलेल्या आहेत.

२० प्रजाती भारतात सापडलेल्या आहेत.
त्यातील ७ प्रजाती सिंधुदुर्गाच्या समुद्र किनाऱ्यावर पाहण्यात आलेल्या आहेत.

बहुतेक समुद्री साप पाण्यामध्येच जगतात
प्रवाळबेटे, कांदळवने, उथळ पाणी, समुद्री गवताची कुरणे, तसेच नद्यांमध्ये समुद्री साप आढळतात. प्रामुख्याने मासे आणि अपृष्ठवंशी जलचर म्हणजे तारले, बांगडे, कोलंबी, शंख हे त्यांचे अन्न आहे.

संपूर्ण जगभरात समुद्री सापांच्या संख्येत घट होताना दिसत आहे. किनारपट्टीचा विकास, हवामान बदल, तसेच व्यापारी तत्वावरील अनिर्बंध मासेमारी ही त्या मागची काही कारणे. सिंधुदुर्गात मासेमारी करणाऱ्यांच्या जाळ्यात किंवा मासेमारीसाठी पडावाच्या मागे पसरलेल्या जाळ्यात अजाणता अडकतात.

निर्मित निधी आणि रसद

दुर्मिळ सामान्य विषारी विनविषारी



●● Beaked sea snake
(*Hydrophis schistosus*)



●● Shaw's sea snake
(*Hydrophis curtus*)



●● Annulated sea snake
(*Hydrophis cyanocinctus*)

SEA SNAKES OF SINDHUDURG

LOCAL NAME: *MARUZO OR MARANDO*

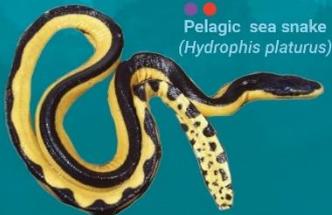
SEA SNAKE DIVERSITY IS THE HIGHEST AMONG MARINE REPTILES WITH OVER 60 SPECIES FOUND OVER THE WORLD.

20 SPECIES ARE FOUND IN INDIA.

7 SPECIES HAVE BEEN OBSERVED ALONG THE SINDHUDURG COAST.



●● Malacca sea snake
(*Hydrophis caeruleus*)



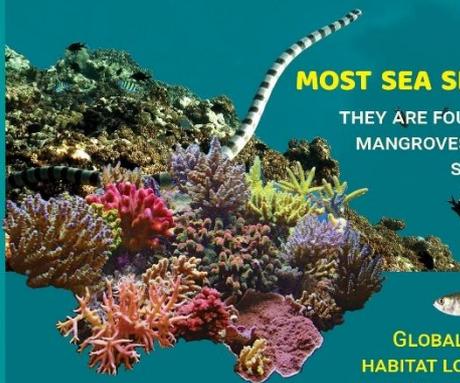
●● Pelagic sea snake
(*Hydrophis platurus*)



●● Viperine sea snake
(*Hydrophis viperinus*)



●● Little file snake
(*Acrochordus granulatus*)



MOST SEA SNAKES LIVE THEIR LIVES UNDERWATER

THEY ARE FOUND IN CORAL REEFS, MANGROVES, SHALLOW WATERS, SEAGRASS MEADOWS, AND EVEN IN RIVERS.

THEIR DIET IS MOSTLY FISH AND INVERTEBRATES SUCH AS SARDINES, MACKERELS, PRAWNS, GASTROPODS ETC.

GLOBALLY, SEA SNAKE POPULATIONS ARE DECLINING DUE TO HABITAT LOSS FROM COASTAL DEVELOPMENT, AS WELL AS CLIMATE CHANGE AND COMMERCIAL OVERFISHING. IN SINDHUDURG, THEY ARE UNINTENTIONALLY CAUGHT IN LARGE NUMBERS, MOSTLY IN TRAWL AND GILL NETS.



Funding and logistics partners



● RARE ● COMMON ● VENOMOUS ● NON-VENOMOUS